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Cloud optical thickness variations during 1983-1991: Solar cycle or ENSO?

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Abstract. Based on a detailed analysis of the cloud data obtained by the International Satellite Cloud Climatology Project (ISCCP) in the years 1983-1991, we show that besides the reported 3% variation in global cloudiness (Svensmark and Friis-Christensen, 1997), the global mean cloud optical thickness (MCOT) also has significant variation which is out of phase with that of the global cloudiness. The combined effect of the two opposing variations may be a null effect on the cloud reflectivity. These results are consistent with the Total Ozone Mapping Spectrometer (TOMS) reflectivity measurements. The MCOT variation is further shown to be correlated with both the solar cycle and the ENSO cycle. Our present analysis cannot distinguish which of the above two provides better correlation, although independent data from the High resolution Infrared Radiation Sounder (HIRS) from 1990 to 1996 favor the solar cycle. Future data are needed to identify the true cause of these changes.

Introduction

Sunspot-climate correlations were first suggested by the renowned astronomer Sir William Herschel nearly two centuries ago [Herschel, 1801]. In the last two decades there have been increasing numbers of reports on the possible correlations between solar variations and climate [see e.g. Wilcox, 1975; Dickinson, 1975; Moses *et al.*, 1989; Tinsley and Deen, 1991; Tinsley, 1997]. Recently, a large variation (3-4%) in global cloudiness was found to be highly correlated with the solar cycle [Svensmark and Friis-Christensen 1997]. This finding, if confirmed, has significant implications on the solar-terrestrial interaction [Svensmark and Friis-Christensen, 1997; Tinsley, 1997]. The dataset used in their work is the International Satellite Cloud Climatology Project (ISCCP) [Rossow and Schiffer, 1991] cloudiness data. Since cloudiness is defined as the cloud occurrence frequency in ISCCP, it does not have information on cloud properties. However, cloud radiative properties, e.g. cloud optical thickness, are essential for assessing the radiative effects of the cloud variations. In our work, we analyze the ISCCP cloud optical thickness data to get a more complete understanding of cloud variations during that period.

We further use the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) reflectivity data [McPeters and Labow, 1996] to check the results from ISCCP. The TOMS instrument measured the backscattered solar radiance in the ultraviolet, from which reflectivity was derived. While not designed for measuring clouds, TOMS reflectivity outside of ozone absorption bands (e.g. at 360 nm and 380 nm) contains information on clouds [Eck *et al.*, 1987]. The reason is that the Earth's UV reflectivity, after subtracting Rayleigh scattering, is primarily determined by the surface and the clouds. Because the global surface reflectivity is believed to be stable on decadal timescale [Brest *et al.*, 1997], variations in the TOMS reflectivity reflect the cloud reflectivity variations. Since the cloud reflectivity is determined by both the cloudiness and the cloud optical thickness, we can use the TOMS data to check the derived variations in cloudiness and the cloud optical thickness from ISCCP data.

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Data and Results

ISCCP-C2 monthly averaged cloud data are used to derive secular variations in the cloud optical thickness. The spatial resolution is 2.5° × 2.5° in latitude and longitude and the time period is July 1983 to June 1991. Cloud optical thickness data were retrieved from the measured visible radiance using radiative transfer models [Rossow and Schiffer, 1991]. Following Svensmark and Friis-Christensen's work, we only use the data within 60°S and 60°N latitude.

We define the Mean Cloud Optical Thickness (MCOT) as the cloud optical thickness averaged between 60°S and 60°N latitude using the area and the cloudiness as weights. The MCOT may be regarded as a global measure of how dense the clouds are. After subtracting the mean annual cycle, the anomaly time series are smoothed using twelve month running mean. Due to the calibration problem in ISCCP-C2 data [Klein and Hartmann, 1993], we construct the anomaly time series for the global surface reflectivity using the ISCCP surface reflectivity data between 60°S and 60°N and use them as the reference to carry out a self calibration. Because the earth surface reflectivity is believed to be stable during 1983-1991 [Brest *et al.*, 1997], the interannual variations in the global surface reflectivity are attributed to instrumental effects. The self calibration is carried out in the following steps. We first calculate the reflectivity effects of the MCOT variations using a simple formula from two-stream radiative transfer models:

$$A_{Cloud} \approx \frac{\tau_{sw}}{(1-g)^{-1} + \tau_{sw}}$$

where g is the asymmetry factor, and τ_{sw} is the cloud optical thickness [Baker, 1997]. Since the calibration problem is mainly caused by changes in instrument gain [Brest and Rossow, 1992], we normalize the global surface reflectivity variations to the reflectivity variations due to MCOT changes. The normalized surface reflectivity variations are then subtracted from the MCOT-caused reflectivity variations. The self-calibrated results are converted into MCOT variations and shown in Fig. 1a. During 1983-1991, MCOT shows variations out of phase with those of the global cloudiness, which were

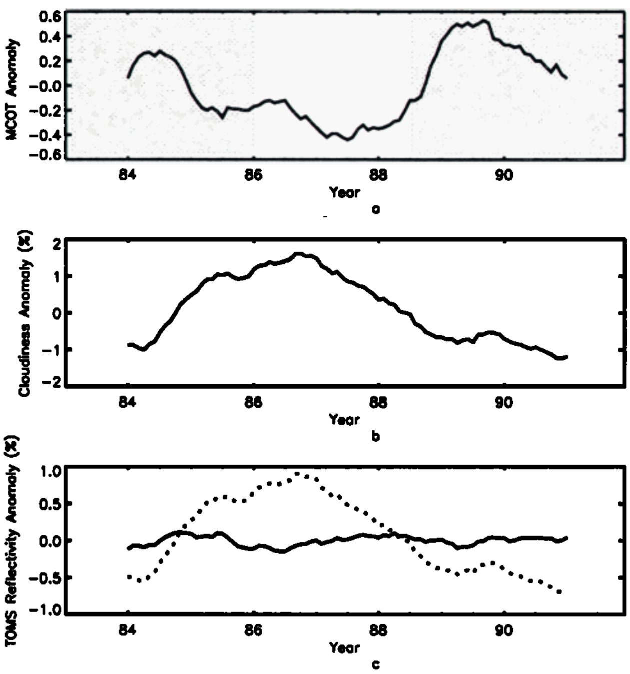

Figure 1. Secular variations of (a) ISCCP MCOT, (b) ISCCP global cloudiness, (c) TOMS reflectivity. Dotted line in (c) is the estimated reflectivity variation caused by the global cloudiness variation given in (b). The secular variations are obtained by applying twelve months running mean after removing the mean annual cycle. The unshaded region in (a) is the time period during which the calibration problem is not significant.

reported by Svensmark and Friis-Christensen [1997] and are shown here in Fig. 1b. The peak to valley variation of the mean cloud optical thickness is ~1.

It is known that the ISCCP calibration problem is mainly two downward steps connecting three periods with small drifts [Brest *et al.*, 1997]. Each 'step-down' is cause by a transition of polar orbiters, i.e. from NOAA-7 to NOAA-9 in early 1985, and from NOAA-9 to NOAA-11 in late 1988. After removing season cycles from global surface reflectivity, we find that the ISCCP surface reflectivity measurements are quite stable from January 1986 to June 1988. This indicates that the MCOT results during that period (unshaded region in Fig. 1a) do not have significant calibration problems. During the other time periods, a quantitative assessment is only possible after the future release of the re-calibrated ISCCP-DX data. However, given that MCOT between 60°S and 60°N is ~6, the estimated 0.3 change in MCOT during 1986-1988 is already a significant change in global cloud radiative property.

The aforementioned calibration problem raises the need for an independent dataset to check the results from ISCCP. To do so, we further analyze the high resolution (1° × 1.25° in latitude and longitude) Nimbus-7 Total Ozone Mapping Spectrometer (version 7) monthly average reflectivity data from 1983 to 1991 [McPeters and Labow, 1996]. The variations of the global TOMS reflectivity are formed by first subtracting the seasonal cycles from the area-weighted averages of TOMS reflectivity for 60°N-60°S, followed by applying 12-month running mean. The results are shown in Fig. 1c, along with crude estimates of the reflectivity effects due to global cloudiness variations (dotted line). Given that the UV reflectivity of clouds is ~56% [Eck *et al.*, 1987] and the surface UV reflectivity is less than 8% [Herman and Celarier, 1997], crude estimates show that a 3% change in global cloudiness would cause a change ~1.5% in global UV reflectivity, a result that must be compared with the observed variation of less than 0.2%. The striking mismatch between the TOMS reflectivity variations and the ISCCP cloudiness variations can only be explain by significant compensating changes in MCOT which offset the effects caused by cloudiness changes. Due to our simplified self calibration, we are not able to make accurate assessment of the reflectivity effect from the MCOT variations. However, a simple radiative transfer model suggests that the reflectivity effect caused by the derived MCOT variations is of the same magnitude as that caused by global cloudiness variations. Hence, the TOMS results agree with the results from ISCCP data, adding confidence to the derived MCOT variations.

Correlations with solar cycle and ENSO

The correlations between the solar cycle, El Niño Southern Oscillation (ENSO) and the cloud variations are shown in Fig. 2. Besides the reported correlation between global cloudiness and the solar cycle, MCOT seems also correlated with the sunspot cycle. The compensation of the MCOT and the global cloudiness variations in the TOMS reflectivity also suggests such a correlation. If this correlation is real, it implies simultaneous but opposing changes in MCOT and cloudiness caused by the solar cycle. The reason might be the increase of the thin clouds, possible along with the decrease of the thick clouds

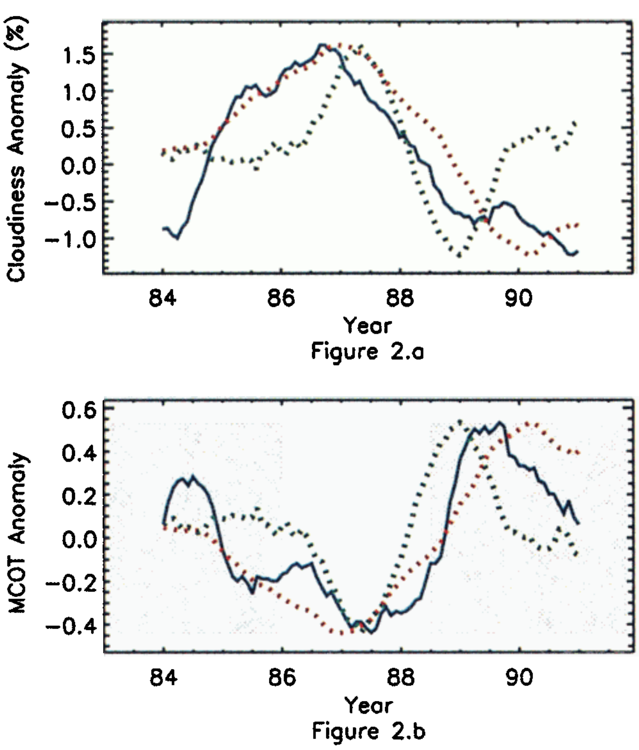

Figure 2. Comparison between secular variations of cosmic ray intensity detected at Climax, CO (red line), ENSO index (green line) and (a) global cloudiness (blue line), (b) global MCOT (blue line) during 1983-1991. ENSO indexes are plotted in reverse scale in (a) and the cosmic ray intensity is plotted in reverse scale in (b). The unshaded region in (b) is the time period during which the calibration problem is not significant.

during solar minimum, i.e. galactic cosmic ray maximum. Thin cloud amounts obtained by the High Resolution Infrared Radiation Sounder (HIRS) observations were reported to vary in phase with the galactic cosmic ray flux from 1990 to 1996 [Menzel *et al.*, 1997]. Furthermore, due to the observed enhanced precipitation caused by enhanced cosmic rays [Stozhkov *et al*, 1995], the amount of thick clouds might be reduced during cosmic ray maximum due to enhanced precipitation. These findings, especially the independent results from HIRS, provide supports for the solar cycle hypothesis.

However, variations in MCOT are also correlated with the ENSO index given that both an El Niño and a solar minimum happened around 1987. The ENSO cycle is known to have significant effects on meteorological parameters [e.g. Ropelewski and Halpert, 1989]. Possible ENSO signals were suggested to exist even in the polar regions [Ledley and Huang, 1997]. Hence, ENSO can cause the derived global MCOT variations, although the detailed mechanisms are still unknown. Given the short time duration and the calibration problem of the data, it is not clear whether solar cycle or ENSO is responsible for the MCOT variations at current stage. Future release of the new stage ISCCP data (DX stage), which extend the data to the year 1996 with revised calibration, will enable us to distinguish between the two possibilities.

Conclusions

Besides the changes in global cloudiness reported by Svensmark and Friis-Christensen [1997], the global mean cloud optical thickness also shows significant interannual variations during July, 1983- June, 1991, which are out of phase with the global cloudiness variations. The results are consistent with the TOMS reflectivity measurements. For the period 1983-1991, the MCOT variations are correlated with both the solar cycle and the ENSO cycle. However, the HIRS cloud data from 1990 to 1996 [Menzel *et al.*, 1997] implies that the solar cycle continues to affect clouds globally through 1996 and makes the solar cycle hypothesis more attractive.

Perhaps the most interesting implications of our work are as follows: (a) the cloudiness and cloud optical depth vary together in such a way that the reflectivity remains approximately constant, (b) the variations in cloud optical thickness may be due to the superposition of different changes in the thick clouds (e.g. an increase) and the thin clouds (e.g. a decrease), resulting in a net decrease. These new findings can be subject to critical tests as the coverage, quality and duration of cloud datasets improve.

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